Ameren Labadie Energy Center Thermal Discharge Best Available Technology Economically Achievable Analysis

Project No. 103550

Final
3/15/2018

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prepared by

Burns & McDonnell Engineering Company, Inc.

INDEX AND CERTIFICATION

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Report Index

Certification

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LIST OF ABBREVIATIONS

Abbreviation	Term/Phrase/Name
AACE	Association for the Advancement of Cost Engineering
ACC	air cooled condensers
ACHE	air cooled heat exchangers
AFUDC	Allowance for Funds Used During Construction
Ameren	Ameren Missouri
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAT	Best Available Technology Economically Achievable
BPS	Brayton Point Station
Burns & McDonnell	Burns & McDonnell Engineering Company, Inc.
FAA	Federal Aviation Administration
HP	horsepower
HVAC	heating, ventilation, and air conditioning
Labadie	Labadie Energy Center
MCC	Motor control center
MGD	million gallons per day
MMBtu	million British thermal units
MS	Merrimack Station
MW	megawatt
MWHR	Megawatt-hour
NPDES	National Pollutant Discharge Elimination System
NPV	net present value

Abbreviation	Term/Phrase/Name
O&M	operating and maintenance
PA	plume abated
PM	particulate matter
$PM_{2.5}$	particulate matter with a diameter less than 2.5 microns
PM_{10}	particulate matter with a diameter less than 10 microns
PSD	Prevention of Significant Deterioration
TMY	typical meteorological year

1.0 INTRODUCTION

1.1 Purpose

Union Electric Company d/b/a Ameren Missouri (Ameren) owns and operates the Labadie Energy Center (Labadie) which is located near Labadie, Missouri on the Missouri River about 50 miles upstream of St. Louis. Labadie entails four 600 megawatt (MW) pulverized coal units that use a once-through cooling water system to condense turbine exhaust steam and to provide plant auxiliary cooling water. The once through cooling water system withdraws water from the Missouri River and pumps it through unit condensers to an artificial channel, which discharges the water back to the Missouri River. Labadie is among the largest coal-fired power plants in the United States, providing power to approximately 1.5 million people.

Burns & McDonnell Engineering Company, Inc. (Burns & McDonnell) was retained to conduct a thermal discharge Best Available Technology Economically Achievable (BAT) analysis to (a) identify the range of alternative cooling technologies generally available for use in the electric power industry, (b) estimate the potential thermal load reduction associated with those alternative control technologies if used at Labadie, (c) perform a screening level cost and impact to plant performance estimate for each of the reviewed technologies, (d) identify the non-water quality environmental implications of each alternative, and (e) determine more detailed cost estimates for those alternatives determined to represent a reasonable and appropriate range in terms of thermal load reduction, cost and overall environmental impact. The following factors were considered as part of the BAT analysis:

1. The age of the equipment and facilities involved
2. The processes employed
3. The engineering aspects of the application of various technologies
4. Process changes and in-plant controls
5. Non-water quality environmental impacts, including energy requirements
6. Total costs of technologies in relation to effluent heat reduction

1.2 Qualifications

Burns & McDonnell is an engineering firm founded in 1898 and today consists of more than 6,000 employees. Burns & McDonnell provides detailed design and construction services for the electric utility industry on all types of generating plants and processes including the cooling and thermal discharge systems. Burns & McDonnell has a team of plant performance engineers, civil, structural, mechanical, electrical, construction engineers, aquatic ecologists, fisheries biologists, National Pollutant Discharge

Elimination System (NPDES) permitting specialists, and hydrodynamic and hydraulic modelers, who have worked together in power plant design and construction including projects to obtain compliance at existing thermal discharges as well as design of new discharges at electrical generating facilities throughout the United States. Burns & McDonnell has direct experience designing and estimating power plant cooling system retrofit projects using each of the feasible control technologies described in this report. Burns & McDonnell is particularly well-positioned to conduct the analysis of this report due to its extensive first-hand experience with Labadie over many years.

2.0 EXISTING COOLING SYSTEM

2.1 Age of Equipment & Process Employed

Labadie consists of four generating units with a net capability of 2,433 MW. The first unit started operating in May 1970 and the plant was fully operational in June 1973. The typical annual generation capacity is approximately seventeen million megawatt hours (17,000,000 MWHR). Labadie was designed, and is operated, as a base load plant with once-through cooling with an artificial discharge channel.

The plant's cooling water intake structure consists of four cells, one for each unit. The intake structure is designed to withdraw up to 1,438 million gallons per day (MGD) of water and averages 966 MGD. Cooling water withdrawn from the Missouri River via the intake structure is passed through condensers (one for each unit), other heat exchangers and the artificial discharge channel before being discharged to the Missouri River. More specifically, water from the four condenser units flows through four eight-foot diameter pipes to a seal well, where the water flows over a weir into the 0.22-mile artificial discharge channel. A warming line recirculates a volume of heated water back to the intake structure to prevent ice buildup in the winter.

Since the original construction of the plant, there have been several upgrades to equipment involved with the thermal discharge of the plant. All four condensers have had original brass tubes replaced with stainless steel tubes. The tube replacement allowed for more water flow by reducing wall thickness while maintaining thermal conductivity. The tube replacement also improved erosion and corrosion resistance. Additionally, circulating water pump impellers are replaced every few years due to wear and these pumps have been upgraded to a more efficient design. All steam turbine sections (HP/IP and LP) have been upgraded from original Westinghouse and GE turbines to higher efficiency Alstom (GE) turbines.

3.0 PLANT PARAMETERS

This section presents an overview of the plant design, unit design, and evaluation basis that was applied to each of the technologies evaluated.

3.1 Ambient Conditions

The following ambient temperatures were determined based on Burns & McDonnell's professional experience and use of American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and typical meteorological year (TMY) weather data from the weather station nearest Labadie, Spirit of St. Louis station. The 0.4% wet bulb temperature was used as the design wet bulb temperature for the wet cooling technology options and the 0.4% dry bulb temperature was used as the design dry bulb temperature for the dry cooling technology options.

1. Average annual dry bulb temperature: 56.7°F based on TMY3 normals weather data[1]
2. 0.4% of year dry bulb temperature: 95.3°F based on ASHRAE data[2]
3. Average annual wet bulb temperature: 51.1°F based on TMY3 normals weather data[1]
4. 0.4% of year wet bulb temperature: 79.9°F based on ASHRAE data[2]

These ambient parameters are conservative and appropriate for the purposes of identifying and evaluating cooling technology alternatives.

3.2 Plant Cooling System

Plant operating data during the summer months (June through September) for 2016 and 2017 was analyzed to determine the design basis parameters for the plant cooling systems. This data represents actual unit and plant performance based on the most recent equipment changes and conditions.

Units 1 and 2 are substantially similar in design, as are Units 3 and 4. Design differences between Units 1-2 versus Units 3-4 are not believed to be material for the purposes of this report, especially since the low-pressure steam turbine modifications were completed on all units. Therefore, this report assumes all four units to be identical in terms of the following design basis parameters. The differences in unit locations do not impact the below parameters, but were considered in cost estimates developed within this evaluation.

[1] Typical Meteorological Year Data, Spirt of St. Louis Station (2013).
[2] ASHRAE Handbook – Fundamentals, Spirit of St. Louis Station (2013).

1. Maximum summer plant capacity cooling load: 3,101 MMBtu/hr (one unit); 12,404 MMBtu/hr (all four units)
2. This load includes unit condenser heat load and auxiliary cooling loads based on peak summer heat rejection load from operating data.
3. Design cooling water flow: 251,500 gpm (one unit); 1,006,000 gpm or 2,241 cfs (all four units) This cooling flow includes water for the condenser and auxiliary cooling users. It is based on operating data corresponding to the coincident peak summer heat rejection load (above).
4. Summer peak and summer average river water temperatures: 88.1°F (peak), 78.9°F (average) Summer peak temperature is based on the 0.4% incident rate from 15-year operating data for the plant[3] and summer average temperature is based on the average during the summer months (June through September) from the data[1]. The 0.4% incident rate was used to be comparable to the 0.4% incident dry bulb and wet bulb values used as the design basis for the cooling technologies. Both summer peak and average values were used in estimating performance impacts from each technology option. For reference, the maximum measured river (plant inlet) temperature over the last 15 years is 89°F.

These plant cooling system parameters are conservative and appropriate for the purposes of identifying and evaluating cooling technology alternatives.

3.3 Plant Performance

1. Condenser:

   Condenser performance was not directly used in this evaluation because operating data[4] was used which relates steam turbine output to inlet water temperature and flow rate. However, the condenser was modeled using GateCycle® thermal modeling software to validate the operating data, along with steam turbine performance correction curves. The condenser was modeled based on original manufacturer performance curves and data.
2. Steam turbine: 634 MW/unit

   The steam turbine gross output used as the basis of performance impact estimates was based on recent operating data for all four units at 70°F inlet cooling water temperature.

These plant performance parameters are conservative and appropriate for the purposes of identifying and evaluating cooling technology alternatives.

[3] Labadie Operating Data for 2002-2017 for MDNR
[4] Labadie Water Temperature and Output Operating Data

4.0 IDENTIFICATION AND SCREENING OF TECHNOLOGIES

This report section discusses the range of technologies identified to reduce thermal discharges, the screening methodology employed, and the results. The screening methodology is consistent with the BAT analysis approach prescribed by the Clean Water Act which requires that the following be considered: the age of the equipment and facilities involved; the manufacturing processes used; the engineering aspects of the application of the control technologies including process changes; non-water quality environmental impacts including energy requirements; costs; and other factors deemed appropriate. Each of these factors is evaluated and used in the determination to screen technologies forward and in the detailed evaluation of the screened technologies (Section 5.0).

At Ameren's request, Burns & McDonnell reviewed the site-specific thermal discharge BAT evaluations conducted in 2002 for the Brayton Point Power Station in Somerset, Massachusetts (BPS). Burns & McDonnell further reviewed the 2011 draft thermal BAT analysis published for public comment concerning the Merrimack Station (MS) in Bow, New Hampshire. Burns & McDonnell recognizes that each thermal BAT evaluation is site-specific and understands that no authority requires a site-specific thermal BAT evaluation to follow a particular format or methodology, to consider a similar range of alternatives or to arrive at similar conclusions. The referenced prior BAT evaluations (all of which concerned power plants significantly smaller than Labadie) were nonetheless reviewed for comparative purposes at Ameren's request with respect to the identification of potential alternative cooling technologies.

The below-listed range of technologies for reducing thermal discharges from the plant were identified based on Burns & McDonnell's direct experience and knowledge of industry used, commercial-scale cooling technologies employed at electric generating plants. Emerging technologies at the lab or pilot scale and which have not been commercially employed were not considered. Therefore, the range of technologies identified is considered to be comprehensive.

1. Existing Once Through Cooling with Discharge Channel
2. Mechanical Draft Cooling Towers
3. Natural Draft Cooling Towers
4. Dry Cooling (Air Cooled Condensers)
5. Permanent Helper Cooling Towers
6. Temporary Helper Cooling Towers
7. Cooling Pond

Each of these listed alternative technologies was evaluated to assess its overall feasibility if applied at Labadie. The below subparts to Section 4.0 describe values used in the evaluation.

4.1 Heat Load Reduction Levels Evaluated

The "heat load reduction value" is the expected percent reduction in heat load (MMBtu/hr) which would be discharged to the river as a result of implementing each alternative technology. Each of the technologies (except cooling pond) was evaluated at two heat load reduction levels: (a) application of the alternative technology to one unit (the One Unit Level) and (b) application of the alternative to all four units (the Four Unit Level). That is, while each alternative control technology could theoretically be applied to all four Labadie units, or to a portion of only one unit, this report assumes an One Unit Level minimum (cooling pond is based on a portion of one unit). Heat load reduction values are stated for each alternative at both the One Unit Level and Four Unit Level and are estimated at summer peak conditions.

Burns & McDonnell believes these levels represent a reasonable and appropriate range of heat load reduction for each alternative. Heat load reduction values for application of each technology to two or three units were not calculated for this report but, for the purposes of the screening assessment of this report, can be assumed to be relatively linear.

4.2 Total Life Cycle Costs

The total life cycle net present value (NPV) project costs (2018 dollars) were estimated for each alternative. The total life cycle costs include the following:

- Capital costs (described in Section 4.3): life cycle costs are based on capital cost expenditures occurring in 2018 for each alternative
- O&M costs (described in Section 4.4)
- Outage costs (based on Section 4.7)
- Capacity loss (costs) (based on Sections 4.5 and 4.6)
- Loss power revenue (based on Sections 4.5 and 4.6)

The total life cycle costs were based on immediate implementation of each alternative, with capital cost expenditures occurring in 2018. Based on estimated project durations, the outage costs occur in 2018 for the permanent helper cooling towers and in 2019 for all other alternatives. The O&M costs and loss power revenue (includes loss revenue due to auxiliary load and plant efficiency loss) begin in 2019 for the permanent helper cooling towers and in 2020 for all other alternatives.

The total life cycle costs presented in Appendix A were developed using the following economic parameters, which were determined from industry experience unless directed by Ameren to use more conservative values. The values requested by Ameren are within the range of those known to be used by the industry and with Burns & McDonnell experience.

Table 4-1: Life Cycle Cost Parameters

NPV Analysis Parameter	Value	Source/Basis
Analysis Duration	30 years	Ameren / Industry Exp
Cost of Capital / Discount Rate	5.94%	Ameren Economics
Capital Cost Escalation	2.4%	Handy-Whitman Index[5]
O&M Cost Escalation	2.5%	Industry Experience
Capacity Factor (each unit)	82%	Historical Labadie Values
Capacity Value, $/kW	See Appendix C	Ameren Market Projections
Energy Value, $/MWh	See Appendix C	Ameren Market Projections
Outage Cost, $/MWh	See Appendix C	Ameren Market Projections
Cost of Full-Time Equivalent (FTE)	$140,000/yr	Ameren Economics

The total life cycle costs developed as part of this evaluation represent technology retrofit at both the One Unit Level and Four Unit Level. Life cycle costs to retrofit a design within this range, such as two (50%) or three (75%) units, can be assumed to be relatively linear for the purposes of the screening evaluation of this report. However, there will be some non-linear cost behavior since the capital costs makeup a majority of the life cycle costs.

It should be noted that the BPS thermal BAT analysis used a discount rate of 11.8%, which is significantly higher than the discount rate used in this evaluation. However, the discount rate used in this analysis is based on Ameren's current accounting practices and consistent with discount rates observed by Burns & McDonnell for other investor-owned electric utilities. Additionally, the analysis duration of 30 years is consistent with the conservative option developed for BPS. The BPS thermal BAT utilized a constant inflation rate for O&M costs and used forecasted wholesale electricity prices and variable costs to determine power revenue and applicable outage costs. The BPS thermal BAT and supporting documents are unclear on the actual values used for these parameters along with maintenance costs. However, the methodology and sourcing for these parameters are very similar to those for Labadie.

[5] Handy-Whitman Index of Public Utility Construction Costs, 2017

4.3 Capital Costs

An indicative screening-level capital cost estimate, consistent with the Association for the Advancement of Cost Engineering (AACE) Class 5, was developed for each technology alternative at the One Unit Level and Four Unit Level as applied to Labadie. The One Unit Level and Four Unit Level capital costs provide adequate range and "bookend" costs for implementing each technology. The estimates were developed based on Burns & McDonnell's first-hand experience at Labadie, with other projects, and using parametric models and previous projects and quotes as reference. Major design parameters (i.e., circulating water flowrate, steam turbine output, piping lengths, etc.) representing the application at Labadie were utilized to adjust cost factors based on established cost relationships and functions. The major design parameters used to develop the cost estimates are summarized in Section 4.13. Cost scale factors were applied to all major equipment and major material and installation costs to adjust cost groups based on site-specific design parameters. Additionally, primary engineering quantities (i.e., civil quantities for cooling ponds or circulating water pipe linear footage) were developed and used as a basis for cost estimating. Costs were also captured for differences in scope. All cost groups were combined to develop screening level total direct costs. St. Louis area specific labor rates were considered to adjust associated costs.

Indirect and other costs were determined based on recent similar projects and include the following.

- Construction management (including managing of multi-sub contracts) based on the size of the project and recent Burns & McDonnell projects
- Engineering costs based on the size of the project and recent Burns & McDonnell projects
- Start-up management and materials based on project size and application
- Escalation during project duration

All sales taxes and financing fees are excluded from the estimates, except for Allowance for Funds Used During Construction (AFUDC). AFUDC of 6% was included for every alternative.

Project contingency (20 percent of total direct and indirect costs) was included to cover accuracy of pricing, commodity estimates, and omissions from the defined project scope. This contingency is not intended to cover changes in the general project scope (i.e., addition of buildings, increased redundant equipment, addition of systems, etc.) nor major shifts in market conditions that could result in significant increases in contractor margins, major shortages of qualified labor, significant increases in escalation, or major changes in the cost of money (interest rate on loans).

Costs were included for traditional owner's costs (four percent of total direct costs, indirect costs, and project contingency) such as project support staff, additional operators, financing, and permitting. This allowance is based on project experience and size and not based on a specific buildup of expected owner costs for this project. Owner contingency was also included as four percent of the total project cost to cover potential change orders that could occur over the project duration.

The costs developed as part of this evaluation represent technology retrofit at the One Unit Level and Four Unit Level, which establish the low and high end of the cost range. Capital costs to retrofit a capacity within this range, such as two (50%) or three (75%) units, were not estimated for this report but, for the purposes of this screening assessment, can be expected to be relatively linear in between the presented low and high costs. However, there will be some non-linear cost behavior due to economies of scale and step changes in design (i.e., circulating water pipe common supply among units and water treatment installation costs – sharing among units).

4.4 Operating and Maintenance Costs

Annual operating and maintenance (O&M) costs were estimated for each technology alternative at Labadie. The O&M estimates are comprised of two main categories: fixed and variable. O&M costs are not inclusive of the entire plant O&M, but are representative of the estimated net additional O&M costs for the operation of added equipment (applicable decommission of existing equipment (i.e., intake screens, existing pumps are included).

Fixed O&M costs include additional staffing and general maintenance costs, which are estimated as a percentage of the capital costs and generally include items such as: electronics; controls; electrical maintenance and replacements; lighting; heating, ventilation, and air conditioning (HVAC); preventative maintenance for pumps, valves, and any other equipment; and equipment inspections.

Variable O&M costs include water consumption and chemical treatment for water and are based on an 82 percent capacity factor. O&M costs exclude wastewater treatment (wastewater chemical feed is included) because wastewater treatment equipment is not included in the design scope. Estimated O&M fixed and variable costs are presented in Appendix A.

O&M costs associated with retrofitting within the One Unit Level and Four Unit Level range, such as two (50%) or three (75%) units, were not estimated for this report but, for the purposes of the screening assessment of this report, can be assumed to be relatively linear, even though the actual relationship is expected to be somewhat non-linear.

4.5 Auxiliary Load Impact

Each technology alternative would add equipment that would impact the auxiliary load of the plant (i.e., which would require power from the plant to operate). Preliminary sizing of equipment was completed for each alternative to estimate the auxiliary load required by the new equipment. The auxiliary load impact reported in Appendix A accounts for reduction in auxiliary load due to decommissioning of some existing equipment (i.e., existing intake pumps), when applicable, and contribute to lost power revenue in the life cycle cost analysis.

4.6 Plant Efficiency Loss

The considered alternative technologies would result in a range of different cooling water supply temperatures or operating backpressures (dry conversion). Preliminary design of the cooling technology equipment was completed for each alternative to estimate the resulting impact to steam turbine output based on change in operating backpressure at summer peak (0.4% incident rate), summer average, and winter average conditions. These impacts were estimated using operating data which relates steam turbine output to inlet water temperature and flow rate. These values are included in the life cycle cost analysis results reported in Appendix A and contribute to lost power revenue.

4.7 Estimated Outage Duration and Costs

Outage durations were estimated for each technology alternative based on Burns & McDonnell experience with Labadie and with similar projects. These expected outage durations were used to determine the cost of lost power sales. These outage durations were considered separately from and additional to normal plant scheduled outages for maintenance (does not include overlap outage benefit) because planned outages are not lined up among multiple units due to the high capacity factors/dispatch of the units. The actual outage duration could vary substantially based on the following potential factors:

- Underground utilities and interferences – these were not investigated as part of this study. Outage duration may increase if there are substantial underground utilities and interferences needing repositioning for tie-ins.
- Condition of existing circulating water pipe and infrastructure. There is potential that some upgrades are required, due to increased system pressure requirements for the new technologies, once piping and infrastructure are evaluated in more detail. If upgrades are required, the outage duration will likely increase significantly.
- Changes to existing equipment requiring modifications or upgrades as a result of new heat rejection system.

4.8 Water Consumption

Water consumption was estimated for each alternative based on the estimated evaporation (towers and ponds/basins) and water losses through water treatment, if applicable. Estimated water consumption was used to estimate variable O&M costs for water treatment for each applicable alternative.

4.9 Equipment Footprint and Height

Footprint and height of each technology alternative were estimated based on preliminary sizing of major equipment and systems and equipment supplier input. Footprints are an important consideration when there are space constraints or interferences. The equipment height is considered when locating near transmission lines and when there are local ordinances regulating allowable heights.

4.10 Particulate Matter Emissions

During an evaporative cooling process, a small portion of liquid water droplets are carried along with the evaporated water (cooling tower drift) in the tower exhaust. Constituents in the makeup water stream can become entrained in these liquid water droplets and these constituents can be emitted as total particulate matter (PM), particulate matter less than 10 microns in diameter (PM_{10}), and particulate matter less than 2.5 microns in diameter ($PM_{2.5}$). Drift occurs with all wet cooling towers and may occur with cooling ponds. The addition of such alternatives would create a potential new source for particulate matter emissions at Labadie, which could potentially trigger Prevention of Significant Deterioration (PSD). A PSD net emissions change evaluation was not completed for this study, but it should be noted that the wet evaporative cooling alternatives would impact particulate matter emissions at Labadie.

4.11 Noise Emissions

The addition of new equipment and movement of water produce additional noise that have potential to increase plant noise emissions. Each technology alternative's noise emissions potential was considered based on its specific noise sources and noise magnitude. The noise emissions potential should be considered when developing a project when local noise requirements and surrounding areas may be impacted. The costs included in the estimates for all screened options do not include noise abatement measures or special noise mitigation costs.

4.12 Vapor Plume Impacts

Traditional wet cooling towers emit plumes of saturated air which can result in ground fog and rime icing during cold conditions, known as plume impacts. These plume impacts can increase safety and Federal Aviation Administration (FAA) permitting risks associated with the cooling tower technology. Each appropriate technology alternative was evaluated for potential plume impacts at Labadie based on consideration of equipment, transmission lines, plant logistics, and winter prevailing wind direction.

4.13 Screening Analysis Design Basis Parameters

Table 4-2 summarizes the major design basis parameters for each technology option evaluated in the screening analysis.

Table 4-2: Screening Analysis Design Basis Parameters

Technology Option	Design Wet / Dry Bulb	Design Approach	Design Flow Rate	New Major Scope			
Once Through Cooling with Discharge Channel	N/A	N/A	251,500 gpm / unit	N/A			
Mechanical Draft Cooling Towers	79.9°F	7°F + 2°F recirc	251,500 gpm / unit	Circ water pumps	Water treatment / chem feed	Collector well makeup	Transformers / electrical feed
Plume Abated Cooling Towers	79.9°F	7°F + 2°F recirc	251,500 gpm / unit	Circ water pumps	Water treatment / chem feed	Collector well makeup	Transformers / electrical feed
Natural Draft Cooling Towers	79.9°F	10°F	251,500 gpm / unit	Circ water pumps	Water treatment / chem feed	Collector well makeup	Transformers / electrical feed
Dry Cooling (ACC)	95.3°F	40°F ITD	Design steam flow	Remove condenser(s)		Transformers / electrical feed	
Permanent Helper Cooling Towers	79.9°F	7°F + 2°F recirc	251,500 gpm / unit	Circ water pumps	Chem feed	Transformers / electrical feed	
Temporary Helper Cooling Towers	79.9°F	11°F + 2°F recirc	251,500 gpm / unit	Rental equipment	Chem feed	Transformers / electrical feed	
Cooling Pond	79.9°F	15°F	251,500 gpm / unit	Periodic chem feed for biological growth		Transformers / electrical feed	

Note: All alternatives also include costs for access road to major equipment (i.e., water treatment area, pump structures)

4.14 Screening Analysis of Each Technology

A description of each technology is provided below along with a table reflecting estimated thermal load reduction, total life cycle costs, capital costs, annual additional O&M costs, costs per load reduction, and a discussion of associated anticipated process changes which would be necessary to retrofit the technology at Labadie. A matrix more fully summarizing the screening analysis is included in Appendix A. The stated heat load reductions are based on peak summer conditions and are expressed in terms of reduction from once through cooling with no discharge channel. The actual heat load reductions would vary with ambient conditions and unit load.

4.14.1 Once-Through Cooling with Discharge Channel

Labadie's existing once-through cooling system extracts water from a body of water, in this case the Missouri River, and passes it through heat exchangers where it absorbs heat (i.e., via the condenser), and then discharges it to a long artificial discharge channel. The channel then discharges water to the original body of water. The artificial discharge channel dissipates some of the heat gained in the cooling stream by transference to the atmosphere via convective and radiative heat transfer. This technology is currently utilized at Labadie and is clearly technically feasible for Labadie with reliable performance. Its continued use would not entail additional costs, additional emissions, or vapor plume impacts.

Table 4-3: Once-Through Cooling with Discharge Channel Screening Results

	One Unit Level	Four Unit Level
Heat Load Reduction	N/A	850 MMBtu/hr (6.8%)[6]
Total Life Cycle Costs	N/A	$0
Capital Costs	N/A	$0
Annual O&M Costs (additional)	N/A	$0
Cost per heat load reduction	N/A	$0/MMBtu

[6] Appendix D.3 of *The Determination of Appropriate Thermal WQBEL and TBEL for the Ameren Labadie Energy Center* dated March 5, 2018 demonstrates a discharge temperature drop of approximately 2%. That Appendix D.3 also illustrates an average temperature drop during the summer months of approximately 1.5%. At peak summer conditions, the plant adds approximately 24.8 F worth of heat to the intake flow and has maximum discharge temperature (to the discharge channel) of 112.9 F. A 1.5% reduction of that maximum temperature yields a 1.7 F temperature drop from the discharge channel. By providing 1.7 F of cooling, the discharge channel provides approximately 6.8% of thermal load reduction (1.7 F / 24.8 F).

4.14.2 Mechanical Draft Cooling Towers

Wet cooling towers reduce the temperature of a water stream by extracting heat from the water and emitting it to the atmosphere via evaporation of a small portion of the water stream. Mechanical draft towers use fans to draw air through falling circulated water. The water falls over fill surfaces, which helps increase the contact time between the water and the air, maximizing heat transfer between the two. A portion of the water evaporates, which cools the remainder of the water. Cooling rates of mechanical draft towers depend upon various parameters, such as air to water surface area which affect the size of the tower and air volume which affect the auxiliary power load, and the volume of water flowing through the tower.

There are two predominate methods for air flow direction in cooling towers, counterflow and crossflow. In crossflow towers the air flows horizontally, across the downward fall of water. In counterflow towers the air moves vertically upward through the fill, counter to the downward fall of water. Counterflow towers require a higher pump head and more maintenance than crossflow towers because of their complex water distribution system. However, they are more efficient than crossflow towers and, therefore, are typically much smaller.

There are two main groups of tower fill: film fill and splash fill. Film fill has a high surface area to volume ratio making it more efficient, but can only be used in relatively clean water (low suspended solids and low biological growth water) so it is typically used in closed loop applications where a treated makeup water source is used with chemical feed systems. The mechanical draft cooling tower alternatives are based on using counterflow high efficiency film fill with a treated makeup water source because the tower cost savings with this type of tower (much smaller than crossflow and splash fill) outweigh the additional costs for water treatment.

Mechanical draft towers are available in a large range of capacities and can be grouped together in assemblies of two or more individual cooling towers or “cells.” Multiple-cell towers can be linear, square, or round depending upon the shape of the individual cells and whether the air inlets are located on the sides or bottoms of the cells. The most efficient and common designs are long rectangular configurations. The mechanical draft tower basis was a long rectangular configuration.

The air exhausted from a mechanical draft tower has a high moisture content from the evaporative heat transfer process within the tower. During cooler ambient condition the moist air can cause fogging near and down-wind of the tower. Fogging can inhibit visibility creating safety issues that impact plant operation. The moist air can also condense and form rime ice on down-wind facilities creating excessive structural load on nearby over-head power lines and slick surfaces creating safety issues that impact plant operations.

Table 4-4: Mechanical Draft Cooling Tower Screening Results

	One Unit Level	Four Unit Level
Heat Load Reduction	3,100 MMBtu/hr (24.99%)	12,400 MMBtu (99.97%)
Total Life Cycle Costs	$271 million	$821 million
Capital Costs	$152 million	$394 million
Annual O&M Costs (additional)	$4.4 million	$15.5 million
Cost per heat load reduction	$87,400/MMBtu	$66,200/MMBtu

Application of this technology to Labadie is expected to entail the costs stated above and in Appendix A. This alternative would also require additional plant staff to operate and maintain the new water treatment systems, chemical feed systems, collector well pumps and equipment, and cooling tower equipment. Additional new solid waste management and disposal costs would be incurred, and a new wastewater discharge stream would need to be permitted for the continuous blowdown from the tower(s). Mechanical draft cooling towers would further involve: consumptive water loss; potentially significant noise emissions increase compared to existing conditions; and the possibility of adverse vapor plume impacts on transmission lines proximate to Labadie.

This technology has been implemented at other power plants at sufficient scale and can be deemed technologically feasible for Labadie for screening purposes. Further detailed analysis may identify factors precluding application of this alternative to Labadie.

4.14.3 Plume Abated (Hybrid) Mechanical Draft Cooling Towers

Plume abated towers are a form of a mechanical draft cooling tower with hybrid cooling characteristics. These towers have very similar designs and operations to non-plume abated mechanical draft cooling towers discussed in Section 4.14.2. However, they reduce visual plumes by reducing the exhaust air relative humidity. Plume abatement can be done various ways, specific to each supplier. Some methods include mixing dry ambient air with the wet air leaving the tower fill to reduce the moisture in the exhaust air. Other methods include using coils to cool a portion of the water by a dry method to reduce overall evaporation and moisture in the exhaust air, which is why these towers are considered a form of hybrid (wet and dry) cooling towers. These are the most cost-effective hybrid towers for a retrofit, and therefore other types of hybrid cooling (i.e., parallel hybrid cooling) were not evaluated. By reducing the relative humidity of the exhaust air, the plume abated towers dramatically reduce the potential development of ground fog and rime icing (plume impacts).

This alternative is very similar to the mechanical draft cooling tower alternatives, with similar tower locations, circulating water pipe routing, and water makeup and treatment design.

Table 4-5: Plume Abated Mechanical Draft Cooling Tower Screening Results

	One Unit Level	**Four Unit Level**
Heat Load Reduction	3,100 MMBtu/hr (24.99%)	12,400 MMBtu (99.97%)
Total Life Cycle Costs	$310 million	$953 million
Capital Costs	$186 million	$509 million
Annual O&M Costs (additional)	$4.4 million	$15.5 million
Cost per heat load reduction	$100,000/MMBtu	$76,900/MMBtu

Application of this technology to Labadie is expected to entail the costs stated above and in Appendix A. This alternative would also require additional plant staff to operate and maintain the new water treatment systems, chemical feed systems, collector well pumps and equipment, and cooling tower equipment. Additional new solid waste management and disposal costs would be incurred, and a new wastewater discharge stream would need to be permitted for the continuous blowdown from the tower(s). Plume abated cooling towers would further involve: consumptive water loss (less than for mechanical draft cooling) and potentially significant noise emissions increase compared to existing conditions. This technology would reduce the potential vapor plume impacts associated with traditional mechanical draft cooling towers.

This technology has been implemented at other power plants at sufficient scale and can be deemed technologically feasible for Labadie for screening purposes. Further detailed analysis may identify factors precluding application of this alternative to Labadie.

4.14.4 Natural Draft Cooling Towers

Natural draft towers are a form of a wet cooling tower configured in a vertical hyperbolic stack configuration and rely on differential air density to achieve air flow through the tower. These towers have no fans. Air at the base of the tower is heated by the cooling water flowing through the tower fill, thus making it less dense than the ambient air. These towers need to be extremely tall, often more than 500 feet in height, to achieve the stack effect. As hot air moves upwards through the tower, cooler ambient air is drawn into the tower through an inlet at the bottom and passes by water falling over fill surfaces, which transfers heat from the water to the air.

This alternative is very similar to the mechanical draft cooling tower alternatives, with similar tower locations, circulating water pipe routing, and water makeup and treatment design.

Table 4-6: Natural Draft Cooling Tower Screening Results

	One Unit Level	Four Unit Level
Heat Load Reduction	3,100 MMBtu/hr (24.99%)	12,395 MMBtu (99.91%)
Total Life Cycle Costs	$316 million	$977 million
Capital Costs	$208 million	$581 million
Annual O&M Costs (additional)	$3.9 million	$14.1 million
Cost per heat load reduction	$101,900/MMBtu	$78,800/MMBtu

Application of this technology to Labadie is expected to entail the costs stated above and in Appendix A. This alternative would also require additional plant staff to operate and maintain the new water treatment systems, chemical feed systems, collector well pumps and equipment, and cooling tower equipment. Additional new solid waste management and disposal costs would be incurred, and a new wastewater discharge stream would need to be permitted for the continuous blowdown from the tower(s). Natural draft cooling towers would further involve consumptive water loss and vapor plume impacts (at a higher elevation due to the increased stack height, resulting in minimal ground fog and rime ice) but minimal noise emissions increase compared to existing conditions. This alternative has the potential to raise concerns associated with the stack height.

This technology has been implemented at other power plants at sufficient scale and can be deemed technologically feasible for Labadie for screening purposes. Further detailed analysis may identify factors precluding application of this alternative to Labadie.

4.14.5 Dry Cooling

Dry cooling systems use ambient air as the cooling medium to condense the steam turbine exhaust. There are two main dry cooling options: direct cooling and indirect cooling. Direct cooling systems, known as air cooled condensers (ACC), directly transfer heat from the steam to the atmosphere and condense the steam inside tubes. Indirect cooling systems, sometimes considered air cooled heat exchangers (ACHE), transfer heat from the circulating water (inside tubes) to the atmosphere. Both options utilize fans to force ambient air across finned-tube heat exchangers to increase heat transfer. Dry cooling performance is based on ambient dry bulb temperature, while wet cooling tower performance is based on ambient wet bulb temperature. Consequently, wet cooling typically results in better cooling performance.

Dry indirect cooling was initially considered in this evaluation but was eliminated because it would result in extremely high backpressure that would trip the steam turbine and it would result in exceptionally high costs. Therefore, it was considered infeasible for this application and eliminated from the evaluation.

ACC relies on close coupling the heat exchanger to the turbine to reduce high pressure drops in piping. An ACC requires space to attach a large steam duct on the steam turbine exhaust in place of the wet condenser and to route the steam duct to an area large enough to place the heat exchanger. If investigated in further detail, it is likely this technology would be deemed technically infeasible for Labadie because of one or more of the following: 1) space allocations at the turbine exhaust do not exist to attach the steam duct 2) insufficient space to route steam duct from the turbine to an open area where the ACC can be located 3) steam duct length would be extremely long causing a high pressure drop in the duct, resulting in a steam turbine backpressure which exceeds the alarm/trip.

Table 4-7: Dry Cooling Screening Results

	One Unit Level	Four Unit Level
Heat Load Reduction	3,060 MMBtu/hr (24.66%)	12,240 MMBtu (98.63%)
Total Life Cycle Costs	\$332 million	\$1,067 million
Capital Costs	\$193 million	\$570 million

Annual O&M Costs (additional)	$3.6 million	$11.3 million
Cost per heat load reduction	$108,500/MMBtu	$87,200/MMBtu

This technology is not known to have been used to retrofit an existing power plant, which makes the technical feasibility of this alternative for Labadie questionable. Moreover, Labadie space constraints would likely preclude the necessary close-coupling of the heat exchangers to the turbines. A more remote location is expected to result in high turbine back pressure, likely exceeding turbine trip limits. Therefore, this retrofit alternative is viewed to be technically infeasible at Labadie.

Parallel hybrid cooling (wet and dry cooling) was considered for this evaluation, but was not included for the screening evaluation because it is subject to the same feasibility challenges as the dry cooling alternative, discussed above, with high associated costs. Since plume abated towers can act as a form of hybrid cooling and are more cost-effective than parallel hybrid cooling, and because dry cooling was viewed as technically infeasible for Labadie, parallel hybrid cooling was eliminated as an alternative for the screening evaluation.

4.14.6 Permanent Helper Cooling Towers

The permanent helper cooling tower alternative is like the mechanical draft cooling tower alternative, except it cools untreated water from the discharge channel and returns it to the discharge channel instead of recirculating cooling water through the units. This alternative reduces the heat load to the river but barely reduces the flow discharged to the river (some water is consumed by evaporation). Additionally, this alternative was based on the use of splash type fill because, although less efficient than film fill, splash fill allows the use of untreated river water with high suspended solids without concern for plugging. The helper tower is crossflow to minimize footprint, pump head, and because it is the most cost-effective tower type when using splash fill.

Table 4-8: Permanent Helper Cooling Towers Screening Results

	One Unit Level	**Four Unit Level**
Heat Load Reduction	2,690 MMBtu/hr (21.70%)	10,760 MMBtu (86.76%)
Total Life Cycle Costs	$143 million	$483 million
Capital Costs	$92 million	$291 million

Annual O&M Costs (additional)	$1.1 million	$3.9 million
Cost per heat load reduction	$53,200/MMBtu	$44,900/MMBtu

Application of this technology to Labadie is expected to entail the costs stated above and in Appendix A. This alternative would also require additional plant staff to operate and maintain the new chemical feed systems (periodic), pumps, and cooling tower equipment. This alternative would further involve: consumptive water loss; potentially significant noise emissions increase compared to existing conditions; and vapor plume impacts. This screening analysis identified the possibility of adverse vapor plume impacts on transmission lines proximate to Labadie. The associated outage period would be less than for closed loop mechanical draft cooling. However, the helper tower(s) could be operated only part of the year, such as the summer, which would reduce these requirements and costs.

This technology has been implemented at other power plants at sufficient scale and can be deemed technologically feasible for Labadie for screening purposes. Further detailed analysis may identify factors precluding application of this alternative to Labadie.

4.14.7 Temporary Helper Cooling Towers

The temporary helper cooling tower alternative is like the permanent helper tower alternative, except it utilizes rented temporary towers, pumps and piping rather than permanent facilities. This alternative would still require permanent facility modifications to supply power and foundation for the rental equipment. This technology would only be rented and used when necessary, providing a non-permanent alternative. This technology also has widely variable pricing based on market demand and rental duration.

Table 4-9: Temporary Helper Cooling Towers Screening Results

	One Unit Level	**Four Unit Level**
Heat Load Reduction	2,250 MMBtu/hr (18.12%)	8,990 MMBtu (72.48%)
Total Life Cycle Costs	$188 million	$706 million
Capital Costs	$21 million plus $6.9 million per 3 months	$51 million plus $27.5 million per 3 months
Annual O&M Costs (additional)	$0.5 million	$1.2 million

Cost per heat load reduction	$83,600/MMBtu	$78,500/MMBtu

This technology is not known to have been used to retrofit an existing power plant at a scale approaching the size of Labadie. The technical feasibility of the alternative for Labadie is questionable for that reason alone. Furthermore, this alternative may be technically feasible for one unit, but because of unpredictable market fluctuations in terms of helper tower rental availability and cost, it is likely difficult to procure sufficient rental towers for all four units when they are needed. Given the lack of a pertinent proven prior application and the unreliability of market conditions, this alternative is considered technically infeasible for Labadie.

4.14.8 Cooling Pond

The cooling pond alternative is like the permanent helper tower alternative, except the cooling pond consists of a shallow large body of water where cooling water is circulated from one end to the other to allow the water to cool through surface evaporation and convective heat transfer. The cooling pond drains to the artificial discharge channel. The cooling pond would inherently require a large surface area to cool the water. There is around 600 acres available for a cooling pond. A pond this size would adequately reject a fraction of the heat load of one unit (~65%). Therefore, this alternative is not feasible for the entire plant heat load and was not evaluated for any size larger than a portion of one unit.

A closed loop cooling pond was initially considered as an alternative but was eliminated because there is insufficient land readily available to fully retrofit one unit and because there are no known uses of this technology to retrofit an existing power plant near the size of Labadie.

Table 4-10: Cooling Pond Screening Results

	Portion of One Unit Level
Heat Load Reduction	1,420 MMBtu/hr (11.43%)
Total Life Cycle Costs	$227 million
Capital Costs	$197 million
Annual O&M Costs (additional)	$1.0 million
Cost per heat load reduction	$159,900/MMBtu

Application of this technology to Labadie is expected to entail the costs stated above and in Appendix A. This alternative would also require additional plant staff to operate and maintain the additional pumps and the pond, which would be subject to biological growth which would need to be controlled to maintain pond performance. This requires periodic chemical treatment and cleaning. This alternative would further involve a consumptive water loss.

This technology has been implemented at other power plants at sufficient scale and can be deemed technologically feasible for Labadie for screening purposes. Further detailed analysis may identify factors precluding application of this alternative to Labadie.

4.15 Screening Analysis Results

The alternative technologies were screened based on the criteria and information described in Section 4.14. That screening process (summarized below) identified the following three technology alternatives for more detailed analysis:

A. Once-Through Cooling with Discharge Channel

B. Mechanical Draft Cooling Tower / Plume-Abated Cooling Tower

C. Permanent Helper Cooling Tower

These three alternatives were, for the purposes of the screening assessment, viewed to be technically feasible. They were identified by the screening assessment as the top three technically feasible alternatives in terms of cost per heat load reduction and total life cycle costs. The Four Unit Level of heat load reduction of each mechanical draft cooling tower and permanent helper cooling tower alternative was determined to be above 86%. The screening results for the remaining alternatives are discussed below.

While cooling ponds are proven at the scale of Labadie, such would require unreasonable land acquisition and development. Additionally, conversion to dry cooling (ACC) is identified as infeasible because of space constraints at and near the steam turbines along with challenges of routing large steam ducts without increasing operating pressure above steam turbine limits. Moreover, even were these alternatives (cooling Ponds and dry cooling) technically feasible, they would not be recommended for further evaluation based on their poor cost per MMBtu heat load reduction value and other criterion relative to other alternatives which could achieve the same or superior thermal load reductions. That is, the cooling pond and ACC alternatives respectively ranked last and second to last, for cost per MMBtu heat load reduction. Even though it may be technically feasible, the natural draft cooling tower alternative ranked third to last in that category. The poor rankings of those alternatives mean they are not cost-effective options to reduce heat load to the river compared to other feasible options. Therefore, the cooling pond, dry cooling and natural draft cooling tower alternatives were eliminated from the evaluation for more detailed assessment.

The temporary helper cooling tower alternative poses technical feasibility concerns as well in that the technology is not known to have been applied at a similar scale and would entail likely high variability in terms of cost and equipment availability. Additionally, it did not rank among the top three alternatives in terms of cost per heat load reduction. This alternative was eliminated from the evaluation for more detailed assessment.

The plume-abated cooling tower alternative was merged with the mechanical draft tower alternative for more detailed evaluation.

5.0 DETAILED ANALYSIS OF SCREENED TECHNOLOGIES

5.1 Technologies Screened Forward and Method of Detailed Analysis

The alternative technologies selected from the screening evaluation for a more detailed analysis are considered potentially reasonable and appropriate for Labadie for the following reasons:

- Each is a proven technology at scales equal to or similar to Labadie. These technologies are well understood in the industry.
- Each ranked among the top three of technically feasible alternatives in terms of cost per MMBtu of heat load reduction.
- Each could encompass an appropriate range of heat load reduction (minimum of one unit up to a maximum of all four units)

It is theoretically possible to use different cooling technology alternatives for different Labadie units. However, given the similarity of the units both in terms of design and utilization, there is no apparent basis to apply different technologies to different units. Therefore, neither the screening analysis nor the detailed analyses of this Section 5 considers mixing of different technologies for different units.

The detailed analysis methodology applied to the screened forward alternatives include consideration of many of the same criteria as considered in the screening analysis. However, the detailed analysis went further in the following ways:

- Developed additional design basis for each option to establish more accurate pricing (Class 4 capital cost estimates versus Class 5 in screening analysis)
    - Major mechanical, electrical, and some civil quantities were developed for each option for cost estimating purposes
- Considered additional site-specific criteria which impacted scope and design basis, including, but not limited to the following:
    - Location of equipment because of plume impacts and site constraints
    - Elevation impacts and requirements
    - Existing electrical feed limitations

- Budgetary quotes and sizing information were solicited for major equipment including cooling towers and transformers

5.2 Detailed Analysis

The narratives of each technology evaluated in the detailed analysis, which are included later in this Section 5.2, focus on the Four Unit Level reduction option since they require the most extensive changes. The One Unit Level reduction option would be similar in scope, but scaled down for just one unit.

5.2.1 Detailed Analysis Design Basis Parameters

Table 5-1 summarizes the design basis used for each screened forward option.

Table 5-1: Detailed Analysis Design Basis Parameters

Technology Option	Once Through Cooling with Discharge Channel	Mechanical Draft / PA Cooling Tower (Low / High)	Permanent Helper Cooling Tower (Low / High)
Tower Type	N/A	Counterflow, H/E fill	Crossflow, splash fill
Number of Cells (per tower)	N/A	20 – mech draft / 28 – plume abated	21
Tower Dimension (each)	N/A	480 ft (L) x 88 ft (W) / 672 ft (L) x 98 ft (W)	672 ft (L) x 75 ft (W)
Design Wet Bulb	79.9°F	79.9°F	79.9°F
Design Approach (+2°F recirc allowance)	Varies with river temperature	7°F	7°F
Design Range	24.8°F	24.8°F	24.8°F
Water Flow Rate (each)	251,500 gpm	251,500 gpm	251,500 gpm
Drift	N/A	0.0005%	0.0005%
Plume Abatement	N/A	Included for PA option	N/A
Level	N/A	Level 1	N/A
Design	N/A	35°F dry bulb, 90% RH	N/A
Plant Modifications	N/A	Upgrade condenser waterboxes Several specialized tie-ins for large circ water pipe Electrical modifications	Electrical modifications
Circ Water Pipe Largest Diameter	96 inches	138 inches (all units) / 96 inches (one unit)	138 inches (all units) / 96 inches (one unit)
Circ Water Pumps	Existing	New: 2 to 8	New: 4 to 16
Design Flow Rate (per pump)	125,500 gpm	125,500 gpm	125,500 gpm
Design TDH	56 ft	108 ft - 112 ft (varies) / 106 ft - 110 ft (varies) PA	70 ft - 74 ft (varies) / 12 ft – 14 ft (varies)
Water Treatment	N/A	Clarification/filtration (4 COC), chem feed	Chem feed: biological
Raw Water Source	River water	Collector well(s)	River water
Electrical Design	Existing infrastructure	Substation / 345kV xmfr 4160/480swgr/MCC	Substation / 345kV xmfr 4160/480swgr/MCC

5.2.2 Detailed Analysis Costs

Capital costs, O&M costs, and life cycle costs developed from the detailed analysis are presented in Table 5-2.

5.2.2.1 Detailed Analysis Cost Basis

An indicative Labadie-specific screening-level capital cost estimate, consistent with AACE Class 4, was developed for each selected alternative for One Unit Level and Four Unit Level options. Like the screening analysis, the One Unit Level and Four Unit Level capital costs provide adequate range and “bookend” costs for implementing each technology. The estimates were developed based on parametric models using previous projects and quotes as reference. Quantities were developed for circulating water pipe, civil fill, and electrical for each option and used to adjust reference project costs. Budgetary quotes were received for cooling towers, transformers and some other electrical equipment. Remaining equipment costs were developed by scaling and adjusting recent equipment pricing using established cost and design relationships. Installation costs were estimated by adjusting installation hours from recent similar project based on scope, equipment sizes, equipment costs, and quantities. All cost groups were combined to develop screening level total direct costs. St. Louis area specific labor rates were included to adjust associated costs.

The costs developed as part of this evaluation represent technology retrofit for one unit (One Unit Level) and all units (Four Unit Level), which establish the low and high end of the cost range. Class 4 capital costs to retrofit a capacity within this range, such as two (50%) or three (75%) units, are expected to be mostly linear in between the presented low and high costs for the purposes of this Section 5. However, there will be some non-linear cost behavior due to economies of scale and step changes in design (i.e., circulating water pipe common supply among units and water treatment installation costs – sharing among units).

Capital cost estimates for the detailed analysis are summarized in Table 5-2.

Annual fixed and variable O&M costs were estimated for each screened forward alternative. The O&M cost basis for this evaluation was the same as the basis for the screening analysis (Section 4.4).

Estimated O&M costs are presented in Table 5-2.

O&M costs to retrofit a design within the One Unit Level and Four Unit Level range, such as two (50%) or three (75%) units, are expected to be mostly linear in between the presented low and high costs for the purposes of this Section 5.

Life cycle costs were developed for each screened forward alternative using the same methodology used for the screening analysis (Section 4.2) based on the same economic parameters summarized in Table 4-1.

Table 5-2: Detailed Analysis Cost Summary

Item Description	Once Through Cooling with Discharge Channel	Mechanical Draft Cooling Tower[1]	Permanent Helper Cooling Tower
Four Unit Level			
Capital Costs (AACE Class 4)			
Total Direct Costs		\$258,900,000	\$239,600,000
Total Indirect Costs		\$46,800,000	\$36,700,000
Total Project Costs		\$420,500,000	\$380,100,000
O&M Costs		\$14,700,000	\$4,900,000
Life Cycle Costs		\$851,000,000	\$614,000,000
\$/MMBtu Heat Load Reduced		\$68,600/MMBtu	\$57,100/MMBtu
One Unit Level			
Capital Costs (AACE Class 4)			
Total Direct Costs		\$98,600,000	\$82,500,000
Total Indirect Costs		\$27,900,000	\$21,100,000
Total Project Costs		\$174,000,000	\$142,400,000
O&M Costs		\$4,300,000	\$1,700,000
Life Cycle Costs		\$297,000,000	\$210,000,000
\$/MMBtu Heat Load Reduced		\$95,800/MMBtu	\$70,200/MMBtu

Notes: [1] Mechanical draft cooling tower costs are shown because this alternative resulted in lower cost than plume abated tower alternative.

5.2.3 Once Through Cooling With Discharge Channel

The existing once through cooling and discharge channel system requires the lowest auxiliary load and no plant efficiency loss (i.e., it produces the lowest average turbine backpressure), and entails no additional life cycle costs. This method of cooling maintains the current thermal load to the river of 11,560 MMBtu/hr (estimated during peak summer conditions for all units). A portion of the plant heat load is dissipated in the discharge channel (about 6.8%) before reaching the river. This method of cooling is the only non-consumptive method of the screened forward alternatives. It also adds no new wastewater or solids disposal requirements to the environment. This alternative requires no process changes and has no additional environmental impacts.

5.2.4 Mechanical Draft Cooling Towers

The mechanical draft cooling tower alternative would reduce the heat load on the river by an estimated 12,402 MMBtu/hr (at summer peak conditions) when retrofitted for all units. However, accomplishing this would require an estimated $421 million capital expenditure and an estimated **total life cycle cost of $851 million**. This alternative would result in an estimated 6,570 GWh of lost power generated by Labadie over the 30-year duration. Conversion would require new cooling towers, pumps and interconnecting piping, new condenser water boxes, a new makeup water system and new water treatment systems (and chemical feed), new electrical power supply systems, new building structures, and waste disposal cost.

During the detailed analysis it was determined that the location of the towers used in the screening analysis cost basis would likely present significant plume impacts at the plant (safety concerns) and potential excessive rime ice development on the transmission lines, which would threaten plant operations. Therefore, all non-plume abated cooling towers were relocated farther northeast from the plant. Conceptual sketches, SK-001 and SK-002, are provided in Appendix B for the One Unit Level and Four Unit Level options, respectively.

For the Four Unit Level conversion, four new 480 ft x 88 ft concrete cooling tower basins with a 52 ft. tall cooling tower and cooling water pump structures would be required. Additional civil fill would be required for all tower options (mechanical draft, plume abated, and helper towers) to increase elevation above the flood plain. This alternative would require eight new 4,200 HP circulating water pumps in the cooling tower pump structures. The existing intake pumps could be decommissioned. The location of the towers would require over 18,000 feet of interconnecting 138” diameter pipe and 4,000 feet of interconnecting 96” diameter pipe between the cooling towers and the existing cooling water pipe. Based on design data, the existing circulating water pipe should have sufficient design pressure for the expected operating system pressure. However, this evaluation did not consider the actual condition of the existing pipe.

This alternative would require up to eight new specialized tie-ins to large diameter concrete cooling water piping along with an associated plant outage of several weeks. A new makeup water system with pumps and interconnecting piping would be required. It is assumed the new pumps would be installed in new collector wells. A new water treatment system with clarifier and chemical feed systems would be required. The water treatment system would generate sludge which would require a sludge disposal cost. The new cooling tower would recycle water requiring a chemical feed system for water quality control including chlorination, dispersant, inhibitor, acid and a blowdown for water chemistry control. The blowdown would need de-chlorination equipment and would be a new wastewater discharge to the environment.

During the detailed analysis it was determined there is insufficient power feed capacity at the facility for any of the options evaluated. Therefore, the design and cost basis include a new 345 kV substation, 4160 V and 480 V transformers, switchgear and motor control centers (MCC)s. The new electrical loads will also require raceway and cabling. The stated life cycle costs assume the electrical tie-ins would be completed during the same outage as the pipe tie-ins. New control systems would be required for the new mechanical and electrical systems, which would also require integrations to be completed during the outage. New buildings would be required for the water treatment systems and chemical feed systems, and mechanical and electrical equipment.

As described above, it was determined that the tower locations in the screening analysis would likely produce adverse plume impacts near the plant, which could result in safety concerns and threaten plant operation (rime ice on transmission lines). Therefore, without plume abatement, cooling towers should be located farther northeast from the plant to adequately reduce these concerns. As an alternative to locating mechanical draft towers farther from the plant, this analysis considered plume abated tower(s) located closer to the plant. Conceptual sketches of these plume abated alternatives, SK-003 and SK-004, are in Appendix B. It is expected that this plume abated tower alternative would sufficiently reduce transmission line icing concerns (potential icing may occur during extreme weather events). However, the additional cost of plume abated towers is greater than the costs to relocate the mechanical draft towers farther northeast. The plume abated alternative would have estimated **total life cycle costs of $964 million** (an additional $113 million beyond the total life cycle costs for the mechanical draft cooling towers at the locations shown in SK-002). Since the plume abated alternative results in higher costs than the mechanical draft alternative, the mechanical draft alternative is deemed the best alternative between the two for this analysis. Therefore, Table 5-2 summarizes the estimated costs for the mechanical draft alternative.

The mechanical draft cooling tower alternative is expected to have a schedule of about 96 months (eight years) to complete design, permitting, procurement, construction, and startup for all four units. Much of this duration is tied to procurement and construction. This duration is based on completing the first unit conversion and much of the balance of plant work (and all permitting and design) within 48 months. Then, each successive unit is expected to take about 16 months to install, finish associated balance of plant work, complete startup and complete outage tie-ins (separate for each unit). This approach results in an optimized schedule, which reduces overall project duration.

5.2.5 Permanent Helper Cooling Towers

This alternative would reduce the heat load on the river by an estimated 11,960 MMBtu/hr (when operated at summer peak conditions). Accomplishing this heat load reduction would require an estimated $380 million capital expenditure and an estimated **$614 million in total life cycle costs**. This alternative would result in an estimated 6,280 GWh of lost power generated by Labadie over the 30-year duration based on 82% annual capacity factor with towers operating whenever the plant operates. Since these cooling towers would not recirculate water to the units for condenser cooling, their operation would not be required to operate the units. Therefore, these cooling towers could be operated year-round or only operated during the summer.

Plume abated towers were earlier compared to mechanical draft towers located farther from the plant, as summarized in Section 5.2.4, which showed that relocating the towers was the more cost-effective alternative. Therefore, the towers for this alternative were located similarly to the towers for the mechanical draft cooling tower alternative and plume abated options were not evaluated. If the towers were only operated during the summer months, then plume impacts would not be a concern and the towers could be located closer to the plant, which would result in capital cost savings.

Conversion would require similar new equipment as described in Section 5.2.4, except for the makeup water system. The helper tower alternative would not require any water makeup (no collector wells and no water treatment) nor condenser water box upgrades. No-tie ins would be required, but temporary dams would need to be built to construct the new intake and outfalls. However, without some form of permanent dams in the discharge channel, some water will bypass the pump intake to the helper towers and reduce the effectiveness of the helper towers at reducing heat load to the river. Variable gates/dams could be installed in the discharge channel to divert all flow to the helper towers when in operation and then allow for normal flow through the discharge channel when the helper towers are not operating. This scope was not considered necessary for the feasibility of this alternative and was, therefore, not included for this report.

This alternative would require smaller and fewer building structures. Furthermore, this alternative would require 672 ft x 75 ft concrete cooling tower basins with 62 ft. tall crossflow cooling towers and cooling water pump structures at the towers and at the discharge channel. It would include eight new 2,700 HP circulating water pumps at the new discharge channel pump structure and eight new 450 HP water pumps at the tower pump structures. This alternative would also require over 18,000 feet of interconnecting 138” diameter pipe between the cooling towers and the existing cooling water pipe and discharge channel along with over 4,500 feet of 96” diameter pipe.

This alternative would require a small chemical feed system (periodic chlorination and de-chlorination), but no water treatment equipment because of the towers’ splash fill. A new electrical substation with transformers, switchgear, MCCs, and associated cabling would also be required.

The permanent helper cooling tower alternative is expected to have a schedule of about 89 months (over seven years) to complete design, permitting, procurement, construction, and startup for all four units. Much of this duration is tied to procurement and construction. This duration is based on completing the first unit and much of the balance of plant work (and all permitting and design) within 44 months. Then, each successive unit is expected to take about 15 months to install, finish associated balance of plant work, complete startup and complete outage tie-ins. This approach results in an optimized schedule, which reduces overall project duration.

6.0 SUMMARY

The purpose of this report was to identify and compare alternative cooling technologies which are or could be applied at Labadie. The evaluation included selection of technically feasible and commercially available technologies with proven capabilities and assessing their capabilities, costs and impacts as applied to Labadie. The evaluation included review of impacts to cooling flow and heat load discharged to the river, overall environmental impacts, site constraints, costs, plant interconnect outages and impacts on plant output and efficiency.

Once-through cooling with an artificial discharge channel and two alternative technologies were identified as technically feasible and the most reasonable and appropriate for more detailed evaluation. The detailed analysis included more detailed cost estimates based on further review of the site arrangement of the new equipment associated with each alternative, options for addressing cooling tower plume issues, and electrical power supply requirements.

7.0 REFERENCES

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APPENDIX A - SCREENING ANALYSIS SUMMARY MATRIX

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Ameren Labadie Thermal Discharge Evaluation
Rev. 4 - 2/23/18 - Draft

Ameren Labadie Screening Matrix

															Technology Comparative Attributes						
Technologies Evaluated for BAT	Technology Description	*One Unit Level* - Heat Load Reduction	*Four Unit Level* - Heat Load Reduction	*One Unit Level* - Life Cycle Costs	*Four Unit Level* - Life Cycle Costs	*One Unit Level* - Capital Costs	Four Unit Level - Capital Costs	*One Unit Level* - O&M Cost Increase	*Four Unit Level* - O&M Cost Increase	*One Unit Level* - Estimated Auxiliary Load Loss	*Four Unit Level* - Estimated Auxiliary Load Loss	*One Unit Level* - Estimated Tie In Outage	*Four Unit Level* - Estimated Tie In Outage	Level of Risk Increase	Footprint	Height	Vapor Plume	PM Emissions Potential	Water Consumption	Noise Emission	Cycle Efficiency Impact (Excludes aux loads)
Once Through Cooling with Discharge Channel	Existing operation. Open loop circulation of cooling water from intake through condensers to discharge channel.	N/A	850 (6.8%)	$0	$0	$0	$0	$0	$0	0 kW	0 kW	N/A	N/A	No additional risks	None	None	No Changes	No Changes	None to minimal	No change	No impact to cycle efficiency
Mechanical Draft Cooling Towers	Counterflow, induced draft, high efficiency fill, fiberglass, evaporative cooling tower(s): Convert to closed loop cooling. New circ pumps supply cooling water to condenser via new pipe tied to existing supply pipe. New pipe tied to discharge pipe returns water to cooling tower for heat rejection.	3,100 MMBtu/hr (24.99%)	12,400 MMBtu/hr (99.97%)	$271,000,000	$821,000,000	$152,000,000	$394,000,000	$4,400,000	$15,500,000	7,100 kW	25,600 kW	2 to 4 weeks	3 to 6 weeks (can be overlapped or staggered)	Medium: Ice damage on adjacent overhead lines	Base: 3 acres for Low to 8 acres for High; 1.3 acres per tower	Typically 40 to 60 ft	Lower elevation plume; fogging / icing can occur	Base: 5 tpy (low) - 20 tpy (high), based on 4 COC (depends on COC design)	8 to 12 gpm/MW	Moderate: Fan and cascading water noise	$4,100,000 life cycle cost per unit; Estimated 3 MW loss per unit during peak summer conditions
Natural Draft Cooling Towers	Counterflow, natural draft, high efficiency fill, concrete, evaporative cooling tower(s): Convert to closed loop cooling. New circ pumps supply cooling water to condenser via new pipe tied to existing supply pipe. New pipe tied to discharge pipe returns water to cooling tower for heat rejection.	3,100 MMBtu/hr (24.98%)	12,395 MMBtu/hr (99.91%)	$316,000,000	$977,000,000	$208,000,000	$581,000,000	$3,900,000	$14,100,000	3,800 kW	12,500 kW	2 to 4 weeks	3 to 6 weeks (can be overlapped or staggered)	Medium: Poor public perception, field labor intensive	Slightly Smaller than Base	High: > 500 ft	Higher elevation plume; minimal, if any, fogging / icing	Base: 5 tpy (low) - 20 tpy (high), based on 4 COC (depends on COC design)	8 to 12 gpm/MW	Low: Minimal cascading water noise	$10,500,000 life cycle cost per unit; Estimated 7 MW loss per unit during peak summer conditions
Plume Abated (Hybrid) Cooling Towers	Plume abated, counterflow, induced draft, high efficiency fill, fiberglass, evaporative cooling tower(s): Convert to closed loop cooling. New circ pumps supply cooling water to condenser via new pipe tied to existing supply pipe. New pipe tied to discharge pipe returns water to cooling tower for heat rejection.	3,100 MMBtu/hr (24.99%)	12,400 MMBtu/hr (99.97%)	$310,000,000	$953,000,000	$186,000,000	$509,000,000	$4,400,000	$15,500,000	7,500 kW	27,400 kW	2 to 4 weeks	3 to 6 weeks (can be overlapped or staggered)	Low: Reduce ice and fogging risks	Slightly Larger than Base	Typically 60 to 75 ft	Minimal to no plume	Base: 5 tpy (low) - 20 tpy (high), based on 4 COC (depends on COC design)	6 to 12 gpm/MW	Moderate: Fan and cascading water noise	$5,200,000 life cycle cost per unit; Estimated 3 MW loss per unit during peak summer conditions
Dry Cooling (ACC)	Wet condensers are replaced with steam duct and air cooled condenser to reject heat from the steam cycle via air cooling instead of the circulating water loop. Aux cooling system remains as wet cooled system.	3,060 MMBtu/hr (24.66%)	12,240 MMBtu/hr (98.63%)	$332,000,000	$1,067,000,000	$193,000,000	$570,000,000	$3,600,000	$11,300,000	8,200 kW	32,600 kW	3 to 6 weeks	5 to 10 weeks (can be overlapped or staggered)	High: No known conversions to dry cooling; STG exhaust retrofit to steam duct may be infeasible; field labor intensive	Large: 2 to 4 x Base	Typically > 70 ft	No plume	No Changes	None	Moderate: Greatest fan noise and no water noise	$17,900,000 life cycle cost per unit; Estimated 16 MW loss per unit during peak summer conditions

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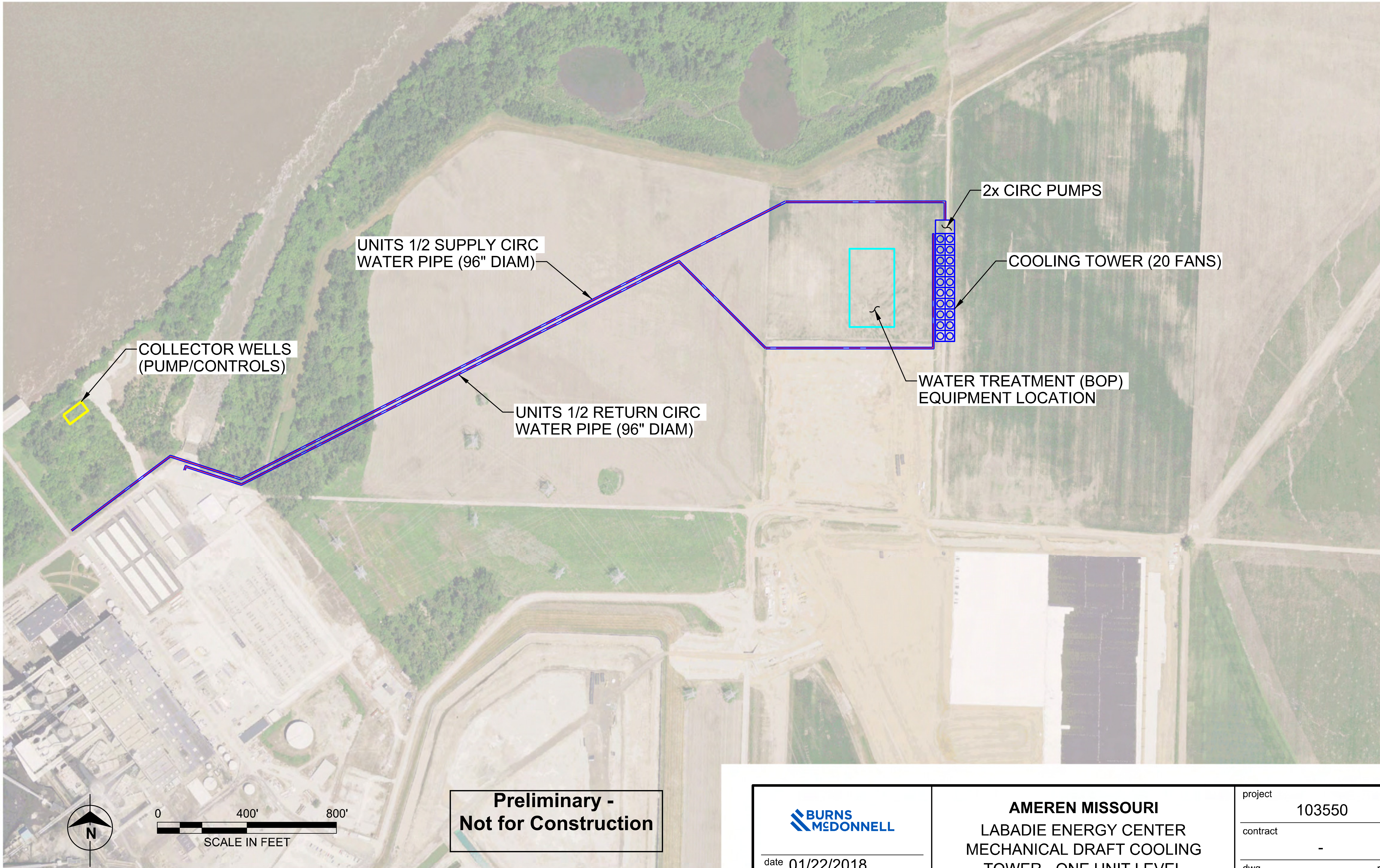
Rev. 4 - 2/23/18 - Draft

Ameren Labadie Screening Matrix

															Technology Comparative Attributes						
Technologies Evaluated for BAT	Technology Description	*One Unit Level* - Heat Load Reduction	*Four Unit Level* - Heat Load Reduction	*One Unit Level* - Life Cycle Costs	*Four Unit Level* - Life Cycle Costs	*One Unit Level* - Capital Costs	Four Unit Level - Capital Costs	*One Unit Level* - O&M Cost Increase	*Four Unit Level* - O&M Cost Increase	*One Unit Level* - Estimated Auxiliary Load Loss	*Four Unit Level* - Estimated Auxiliary Load Loss	*One Unit Level* - Estimated Tie In Outage	*Four Unit Level* - Estimated Tie In Outage	Level of Risk Increase	Footprint	Height	Vapor Plume	PM Emissions Potential	Water Consumption	Noise Emission	Cycle Efficiency Impact (Excludes aux loads)
Permanent Helper Cooling Towers	Crossflow, induced draft, splash fill, fiberglass, evaporative cooling tower(s): Maintain open loop cooling. New pumps draw water from discharge channel to supply water to cooling tower(s) for heat rejection. Water exits cooling tower and gravity drains into discharge channel.	2,690 MMBtu/hr (21.70%)	10,760 MMBtu/hr (86.76%)	$143,000,000	$483,000,000	$92,000,000	$291,000,000	$1,100,000	$3,900,000	7,000 kW	27,800 kW	1 week or less	1 week or less	Low/Medium: Ice damage on adjacent overhead lines, if operated in cold weather conditions.	Slightly larger than Base tower (no water treatment): about 1.5 acres per tower	Typically 40 to 60 ft	Lower elevation plume; fogging / icing can occur	Lower than Base: 1.2 tpy (low) - 5 tpy (high)	8 to 12 gpm/MW	Moderate: Fan and cascading water noise	No impact to cycle efficiency
Temporary Helper Cooling Towers	Supplier installs rental towers and associated equipment to operate temporarily (i.e. summer months). Temporary pumps draw water from discharge channel to supply towers. Towers cool water and release back to the discharge channel.	2,250 MMBtu/hr (18.12%)	8,990 MMBtu/hr (72.48%)	$188,000,000	$706,000,000	$21,000,000 one time cost plus $6,900,000 per 3 months	$51,000,000 one time cost plus $27,500,000 per 3 months	$500,000	$1,200,000	7,100 kW	28,500 kW	1 week or less	1 week or less	Medium: Price and availability of rental towers are variable; Ice damage on adjacent overhead lines, if operated in cold weather conditions.	Larger than Base	Typically 15 to 30 ft	Lower elevation plume; fogging / icing can occur if operated during cold weather - unlikely for temporary towers	Lower than Base: 2.5 tpy (low) - 10 tpy (high)	8 to 12 gpm/MW	Moderate: Fan and cascading water noise	No impact to cycle efficiency
Cooling Pond	Maintain open loop cooling. New pumps draw water from discharge channel to suppy water to cooling pond via new pipe for heat rejection via evaporative and sensible cooling. New pipe returns water from pond to discharge channel by gravity drain.	1,420 MMBtu/hr (11.43%)	N/A	$227,000,000	N/A	$197,000,000	N/A	$1,000,000	N/A	2,500 kW	N/A	1 week or less	N/A	Low/Medium: Requires substantial area of land suitable for conversion to pond.	Largest: 600 acres	Developed at higher elevation than discharge channel	Potential fog and ice near pond	Very low	4 to 12 gpm/MW	Low: minimal water noise	No impact to cycle efficiency
Notes about Factor Columns		*Shown as MMBtu/hr and % reduction in heat rejected to river at peak summer conditions. This will vary with load and ambient/river temperature *Assumes all four units are operating with corresponding units retrofitted with technology (one or all four) *Pond options max heat load reduction is for only 65% of one unit because of space limitations		*30 yr NPV *82% capacity factor *5.94% cost of capital *2.4% capital escalation *Power prices: see App C *2.5% O&M escalation *Capacity value: see App C *$0.05/kgal raw water		*Costs are based on preliminary design for One Unit Level (except only part of One Unit Level for pond alternative)	*Costs are based on preliminary design for Four Unit Level	*Includes fixed and variable O&M *Based on 82% capacity factor *Based on $140,000 annual FTE *Does not include replacement power cost (outage) or lost revenue		*Net aux load impact (some options include decomissioning of intake pumps)								*Does not account for potential PM emissions added from other generation source to compensate for lower power production			*Costs based on 30 yr NPV with assumed operating profile: see Appendix C

APPENDIX B - DETAILED ANALYSIS CONCEPTUAL SKETCHES



Preliminary - Not for Construction

BURNS McDONNELL

date 01/22/2018

designed A. MYERS

AMEREN MISSOURI

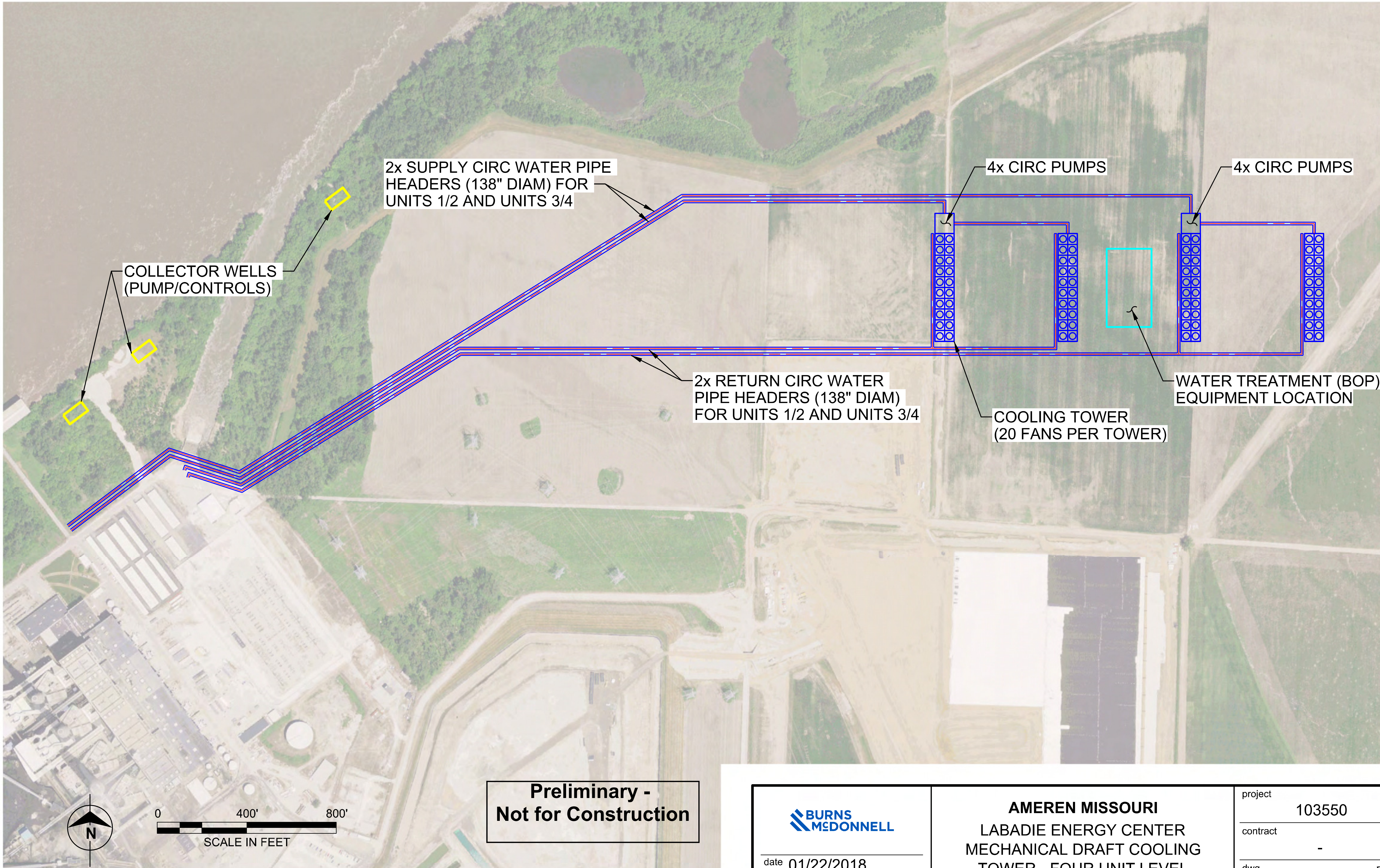
LABADIE ENERGY CENTER
MECHANICAL DRAFT COOLING
TOWER - ONE UNIT LEVEL

project 103550

contract -

dwg **SK - 001**

rev **-**



BURNS McDONNELL

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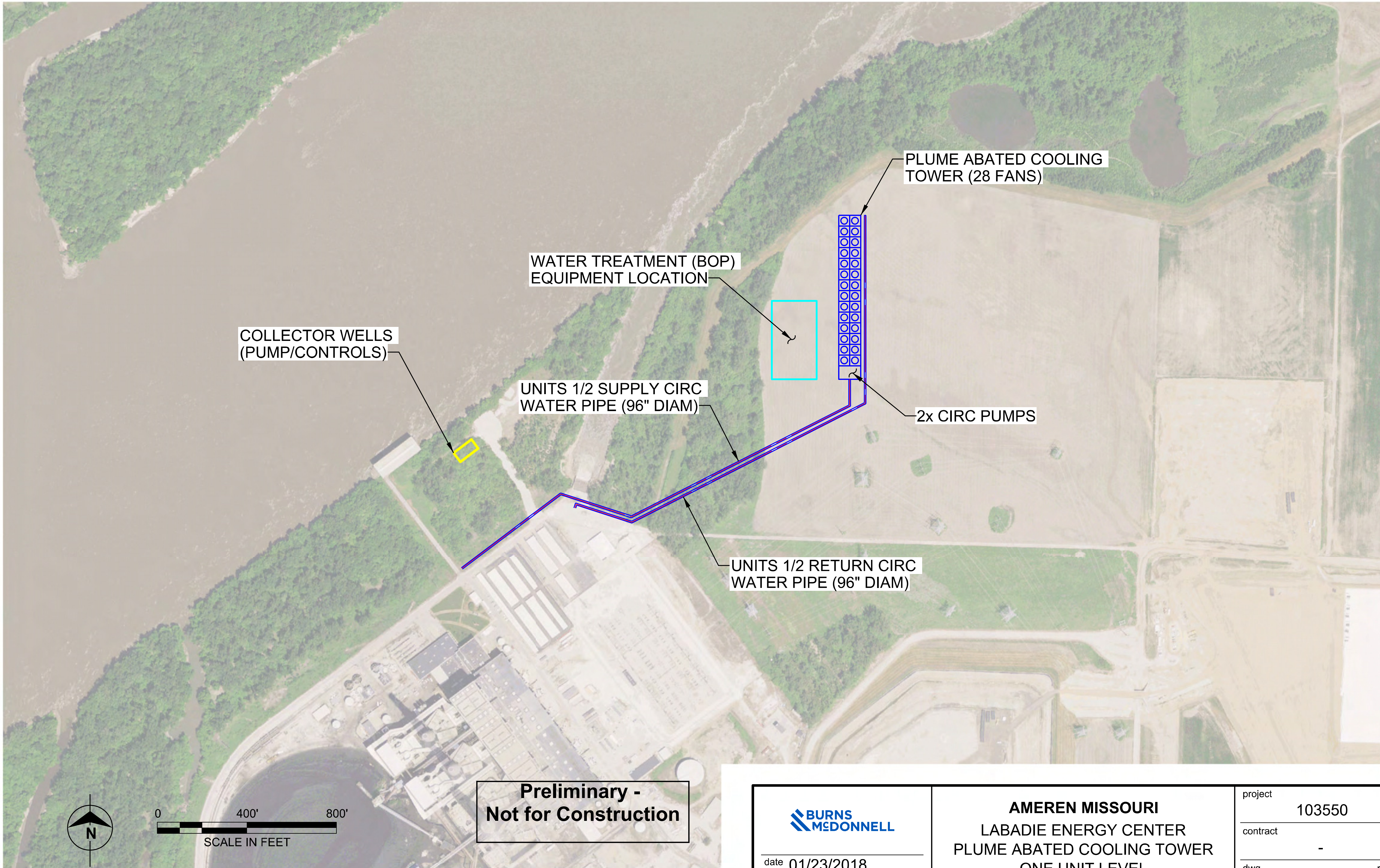

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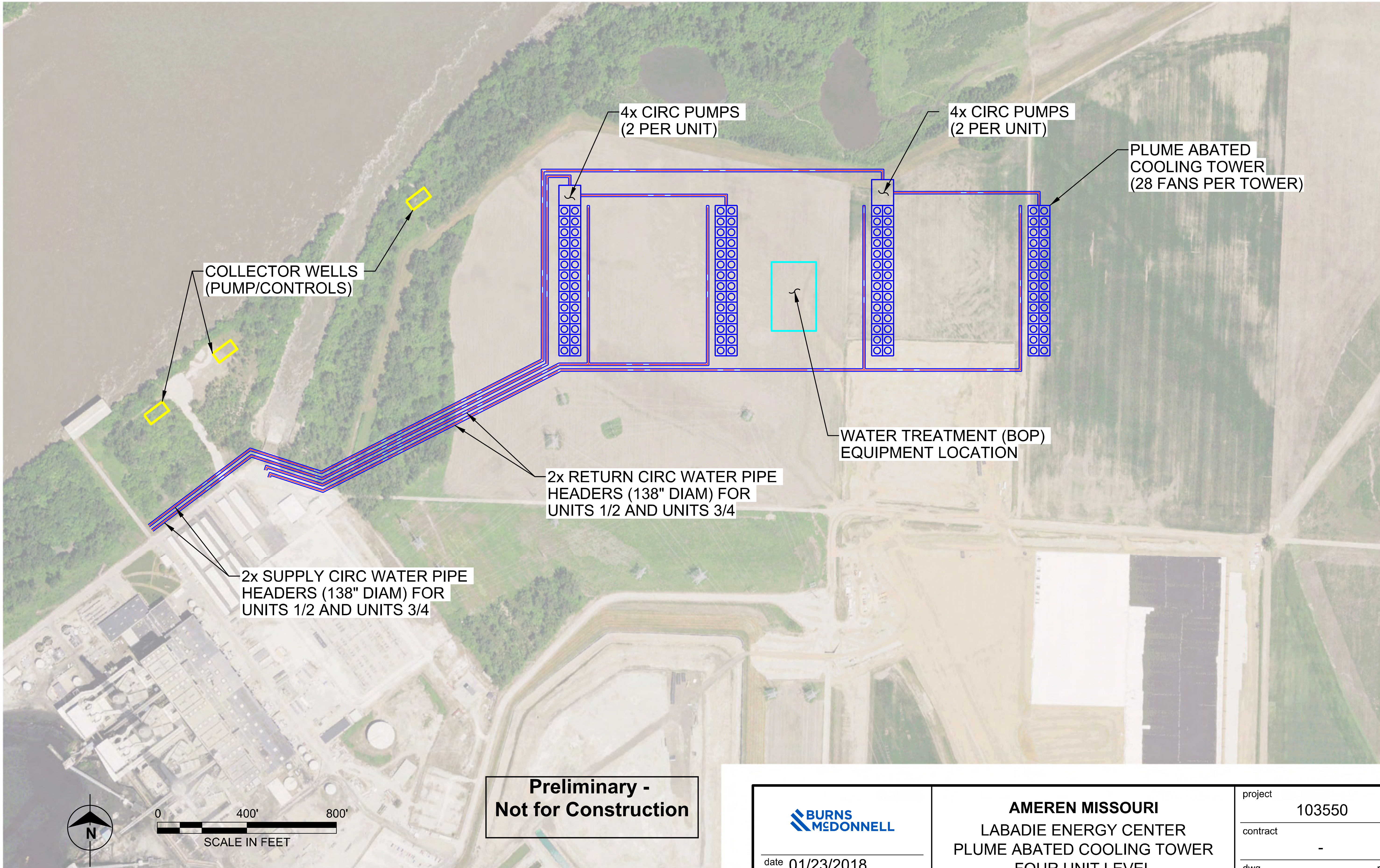

Preliminary -
Not for Construction

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date 01/23/2018		contract -
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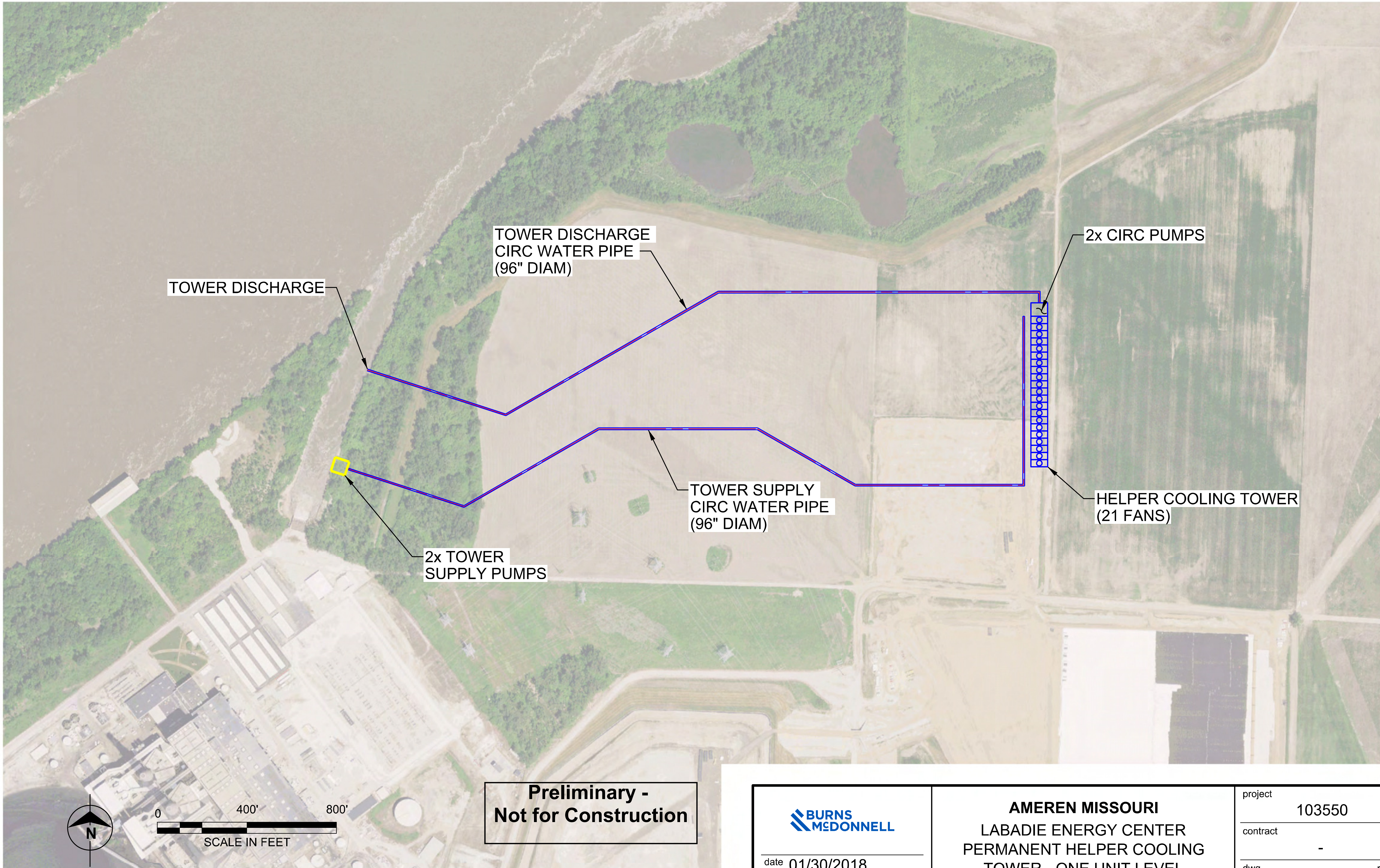


BURNS McDONNELL

date 01/30/2018

designed A. ERICKSON

AMEREN MISSOURI

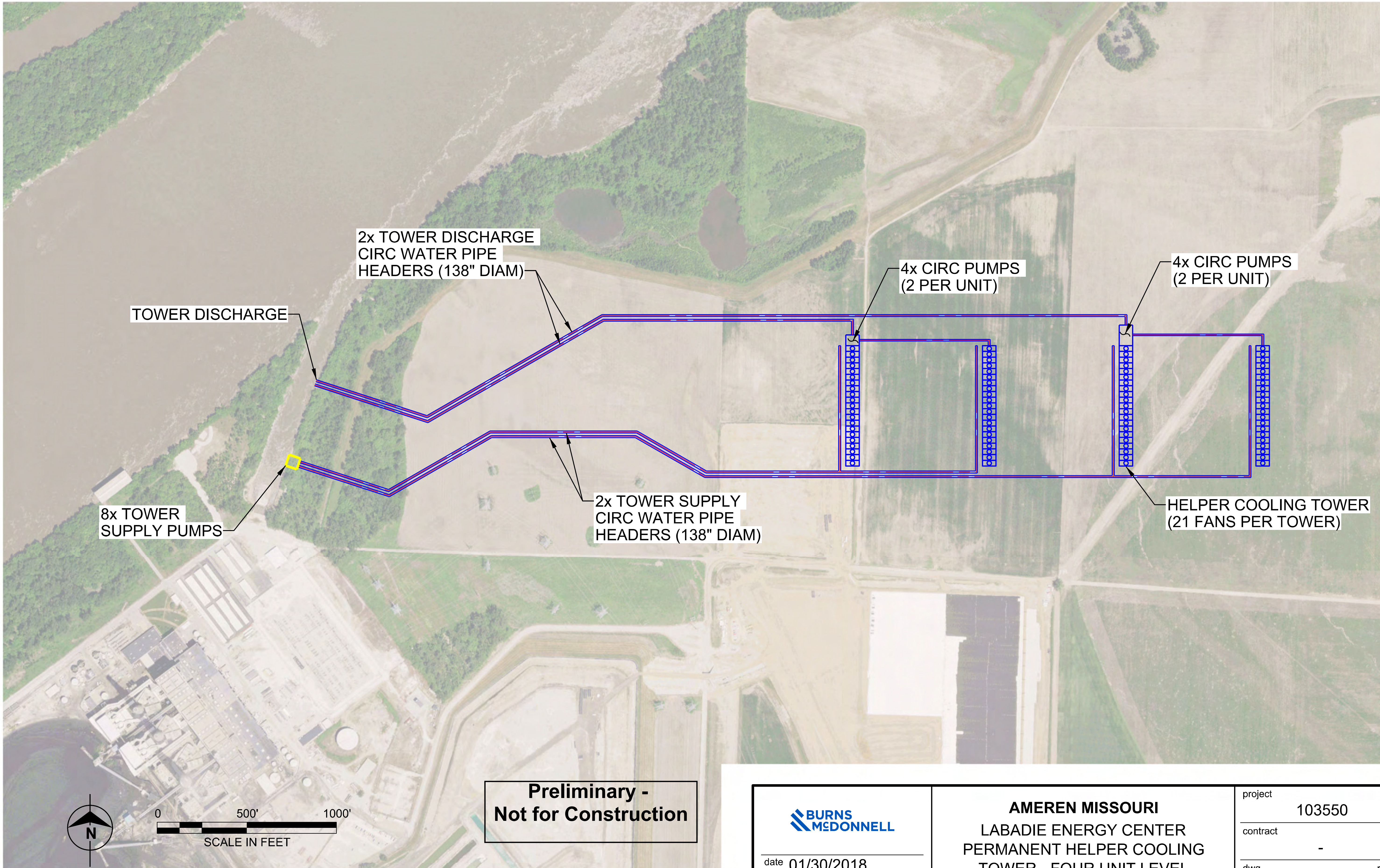
LABADIE ENERGY CENTER
PERMANENT HELPER COOLING
TOWER - ONE UNIT LEVEL

project 103550

contract -

dwg **SK - 005**

rev **-**



Preliminary -
Not for Construction

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date 01/30/2018

designed A. ERICKSON

AMEREN MISSOURI

LABADIE ENERGY CENTER
PERMANENT HELPER COOLING
TOWER - FOUR UNIT LEVEL

project 103550

contract -

dwg **SK - 006**

rev **-**